Reducing Negative Effects from Virtual Environments: Implications for Just-In-Time Training

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Summary

Current U.S. Naval doctrine places increasing emphasis on providing just-in-time training. This means training the deployed sailor when they need the training, wherever they happen to be. This differs from classic training doctrine that calls for placing a completely trained expert in the field. This shift in doctrine is a direct response to reduction in force sizes, necessitating fewer experts and more generalists. Just-in-time training requires the generalists to be somehow brought up to expert standard in the field. One way to fill this requirement is through the use of deployable training systems. In this sense, 'deployable' refers to a system that requires minimal space, demands little if any maintenance, and is easy to set-up. Virtual Environment (VE) training systems, with their inherently small footprint, and fundamental reliance on software rather than hardware solutions, represent a seemingly elegant solution to many of these challenges. However, VE systems bring with them their own unique set of challenges that can negatively impact skill learning during VE exposure, as well as significantly reduce military personnel's ability to perform mission-critical tasks following VE exposure.

For instance, a group of side effects collectively known as cybersickness can be especially debilitating to users during VE training. Symptoms range from the distracting, such as eyestrain and blurred vision, to the performance detracting, such as visual motor coordination and balance disturbances. Cybersickness occurs in approximately 80-95% of individuals receiving virtual training, with up to 30% of the trainees opting to terminate training before completing it. VE exposure can also produce aftereffects such as eyestrain, dizziness, and nausea, that can last more than an hour after a training session, and in about 8% of individuals symptoms can last for more than six hours post session. Prolonged exposure to VEs can lead to distinct physiological changes, such as changes in the resting point of accommodation or even recalibration of perception-action couplings following exposure to visual scenes. These issues become even more critical when using VE systems to deliver deployable, just-in-time training. When these simulations are placed aboard ship, the physical ship motion will be completely uncorrelated to the motion being visually represented in the VE. This discordance will most certainly exacerbate any already existing side/after effects. The net result of these effects is an increased likelihood of users receiving less-than-adequate training *during* VE exposure, and being unfit to perform their duties *following* VE exposure.

It is precisely these compounded effects that current research efforts seek to quantify and to reduce. To this end, two parallel approaches have been pursued. In the first, participants 'flew' a personal computer-based flight simulator in the absence of any physical motion, were exposed to actual ship motion in the absence of any simulator exposure, and flew the flight simulator while deployed aboard a small ship. Results from this

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study indicate that even when benign ship motion and benign flight simulated motion are combined, a physiological degradation can occur. The effects of the uncoupled motion appear additive in nature, but do not cause emergent effects greater than the sum of the individual motions. A second effort, currently in progress, explores the notion of subtracting the physical motion from the visually displayed motion to reduce these negative additive effects. Additional engineering and behavioral studies are planned.

Introduction

Simulation Sickness

It is not known why individuals get sick when exposed to a flight simulator. It has been suggested that flight simulators create a perceptual conflict that results in sickness (Reason and Brand, 1975; Kennedy and Frank, 1985; Kennedy, Berbaum and Lilienthal, 1992). For example, if an individual is flying a visual-only flight simulator, he might perceive that he is moving forward based on the information that the brain is receiving from the visual system. However, his brain would simultaneously receive information from his vestibular and proprioceptive (muscle) systems that correctly identify that in reality he is sitting still. The conflict between information produced by perceptual systems immersed in the simulation and those fixed in reality can produce motion adaptation syndrome (MAS). MAS is a collection of symptoms and side-effects that occur when a human is placed into a novel real or apparent motion environment and tries to maintain spatial orientation and motor coordination within the novel environment.

The majority of simulation-based training in the Navy focuses on the aviation domain. From the Navy's perspective, about one in four pilots report symptoms that last more than an hour after a flight simulation training session, and about 8% report symptoms lasting for more than six hours (Baltzley, et al. 1989). The typical symptoms reported are eyestrain, fatigue, drowsiness, sweating, headache, and difficulty concentrating (Lawson, Graeber, Mead, and Muth, 2002). Moreover, it has been found that exposure to flight simulation can cause measurable changes in motor performance, as 1.5% of pilots report difficulty flying an actual aircraft following exposure to a flight simulator (Ungs, 1989). Approximately 4.6% of trainees develop long-term aftereffects, including balance problems, deficits in eye-hand coordination, persistent difficulty in concentrating and sleeping, and "simulator flashbacks", including visual flashbacks or distortions and continued sense of detachment from reality (Ungs, 1989). These data were generated on land-based simulators and represent a significant source of performance degrading side effects for individuals exposed to these simulators

Sea sickness

At the same time, it has long been known that exposure to ship-like motion can result in sickness. Considerable attention has been placed on the problem since the events of World War II demonstrated the need to move large numbers of troops by sea and the consequential impact of seasickness (Morales, 1949; Bruner, 1955). Early work concluded that linear translations contribute significantly to seasickness (Tyler and Bard, 1947). Later work found that vertical translational oscillation was an accurate predictor of sickness (Lawther and Griffin, 1987). The culmination of years of work regarding provocative ship motion is summarized in MIL-STD-1472C (Figure 43, page 176). This document reveals that vertical oscillation (heave motion) at a frequency between 0.16 and 0.2 Hz (10-12 cycles per minute) tends to provoke seasickness. Lawther and Griffin (1987) present a wider range of provocative frequencies, pointing out that humans are most affected by vertical oscillations in the frequency range of 0.1 to 0.5 Hz (6-30 cycles per minute). Although heave ship motion data do not explain the underlying physiological mechanism of seasickness, they do point to a causal motion factor: how quickly individuals get sick will depend on a combination of the frequency and acceleration characteristics of the heave motion. As with simulator-based sickness, seasickness results in significant decreases in crew readiness.

Combined effects of virtual and physical motion: Decoupled motion environments

Studies of aircrew and flight navigators suggest that they are more susceptible to airsickness than pilots (Royal, Jessen and Wilkens, 1984; Strongin and Charlton, 1991). A study of operators within a Command and Control Vehicle (an armored tracked vehicle containing four workstations within an enclosed crew compartment having no outside view), found worse crew performance and increased motion sickness when operators had to attend to computer screens while the vehicle was moving (Cowings, Toscano, DeRoshia and Tauson, 1999). The performance decrements were attributed to visual fixation during vehicle motion, since visual fixation during the stationary conditions did not produce the decrements. This finding agrees with an earlier report that video displays alone do not disturb operators (Smith, Cohen and Lambert, 1981).

Thus, it is probable that the decoupling between physically experienced motion and visual scene motion may lead to sickness, and perhaps, other negative effects. Nevertheless, despite the trend towards placing training simulations which provide a visually indicated motion stimulus, aboard ships which provide a completely distinct physically indicated motion stimulus, there has been no concerted effort into quantifying the causative relationship between decoupled motion environments and negative effects. This paper reports two research efforts that aim to fill this knowledge gap. The first explores the negative effects of training in a minimally provocative Virtual Environment flight simulation placed aboard a ship with minimally provocative motion. The second focuses on identifying methods for reducing negative effects.

Experiment 1: Minimally provocative simulation, minimally provocative ship motion

Twenty-six males ranging from 33-45 years of age participated in the study, the majority of whom had some form of flight experience. All participants completed a Pre-test and Post-test in a mobile field laboratory (a parked trailer fully equipped as a laboratory and climate-controlled). During each test period, participants had their balance and dynamic visual acuity tested, and symptoms assessed. Between the Pre-test and Post-test, one of three experimental manipulations (independent variable) occurred. Participants either piloted a flight simulator while riding aboard a Yard Patrol (YP) boat (ship + flight sim), rode aboard a YP boat without piloting the flight simulator (ship) or piloted the flight simulator on land (flight sim). Participants completed one condition per day.

During the Pre and Post testing periods three measures were recorded: *Balance*, quantified using the Neurocom Balance Master; *Dynamic Visual Acuity*, quantified by having participants read a visual acuity chart while making yaw-axis head movements; and *Symptom Assessment*, using the Nausea Profile (Muth, Stern, Thayer and Koch, 1996) and the Simulator Sickness Questionnaire (Kennedy, Lane, Berbaum and Lilienthal, 1993).

During the flight sim condition participants used a CRT based simulation (no motion platform) to perform a basic 'follow me' trajectory using joystick and throttle controls. Participants performed this maneuver for one hour. During the ship and ship+flight sim condition, the YP completed 2 clockwise octagons, with one octagon covered in approximately 30 min and each leg of the octagon lasting approximately 3.5 min. Ship speed was held as close to 6 kts as possible and 45^o course changes were made at full rudder (20^o), taking approximately 15 sec to make a course change. Participants were either exposed to a one-hour flight simulation (sim) or listened while seated and blindfolded, to a portion of a book on tape (ship). After ship exposure, participants were wheeled to the mobile field laboratory in wheelchairs to minimize re-adaptation to land due to walking. Ship motion was monitored and recorded using a 6-degree of freedom accelerometer package. The only significant motion recorded by the accelerometer was the roll of the ship during the full rudder (20^o) turns (Figure 1).

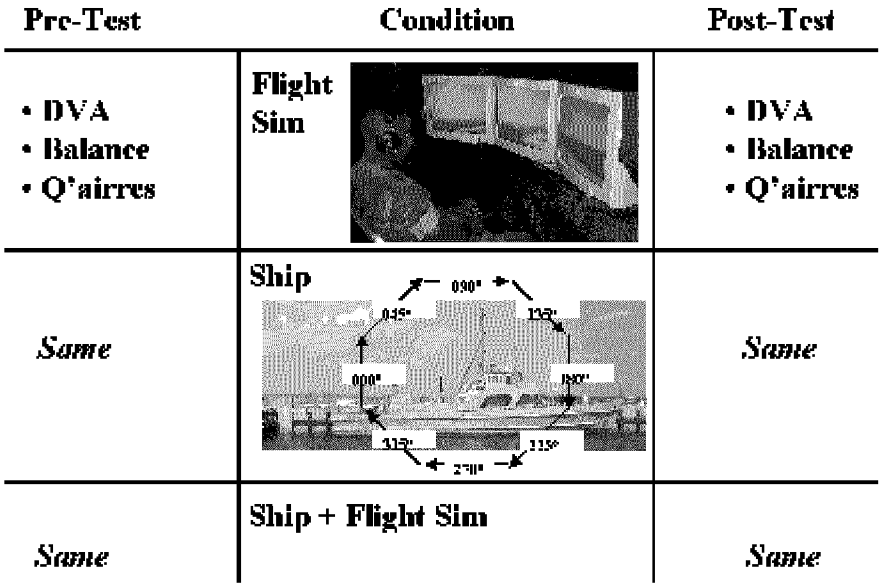

Figure 1: Experiment 1 design. Regardless of condition (flight sim, ship, ship+flight sim), each participant received a Pre-test assessment prior to exposure to the condition and a Post-test assessment following exposure to the condition. The assessment included an evaluation of participants' balance, Dynamic Visual Acuity (DVA) and two questionnaire-based evaluations of sickness.

Due to scheduling logistics, the flight sim condition always occurred first (Day 1), followed by the other two conditions which were counterbalanced across the remaining two days. Thus, for each measure, it is not possible to directly demonstrate an effect of the flight sim condition. The results from the balance testing showed no significant differences between the ship and ship + flight sim conditions. By inference, it is highly likely that sim alone also did not affect balance. Similarly, the results from the symptom assessment were negligible for all conditions: the average nausea profile score was less than 4 out of 100 possible points, while the average simulation sickness questionnaire score was less than 3 out of 45 possible points.

Most interesting was the finding that dynamic visual acuity for the ship condition alone and for the flight sim condition alone each demonstrated a loss of approximately one-half line of acuity, while the ship + flight sim condition showed a summation effect, with a loss of one entire line (repeated measures ANOVA, $p<.05$). These findings are all the more impressive in light of the findings of no significant difference in the other measurements –in particular, with regard to participants' own perception of their state of sickness. First, this suggests that combining dissimilar motion environments –decoupled motion environments- will, in fact, produce distinct negative effects. Second, this finding underscores the insidious nature of these negative effects- trainees can actually leave such an environment assuming themselves to be 'good to go' when in fact, they are in a state of decreased readiness. These results have significant implications for the method through which just in time training is delivered aboard ship, which will be addressed in Experiment 2.

Experiment 2: Methods for reducing sickness in decoupled motion environments

The results from Experiment 1 suggest that, alone, the two motion conditions under investigation do not produce sickness but, when combined, can in fact summate to produce a detectable effect. At first glance, this finding may seem preliminary. However, it is important to realize that the stimuli used were extremely minimal: the VE simulation utilized CRT technology, which is categorically different from the Head Mounted Displays that may be used aboard ship (Cohn, Mead, Giebenrath & Burns, 2002); the simulation was non-provocative, requiring users to follow a pre-set path rather than the more rapid scene changing that would be expected from a true flight simulation; and, finally, ship motion was negligible. Thus, these findings of significance are all the more indicative in light of their being identified in such a benign environment. In order to more completely flesh out the interactions between these two motion environments, a second experiment was performed, in which more provocative motion stimuli, both physical and virtual, were used.

O'Hanlon & McCauley (1974) have suggested that the most provocative type of motion occurs during vertical oscillation (corresponding to heave ship motion) at a frequency of 0.2Hz. A platform (Vertical Linear Oscillator, VLO, Brandeis University's Ashton Graybiel Spatial Orientation Laboratory) that supported this type of motion was developed, allowing for over 6 feet total vertical displacement. As well, a more immerssive simulation was integrated, using a Head Mounted Display unit, projecting a scene that would typically be encountered by a member of ship's crew. Finally, a device for coupling visual scene motion to physical motion was developed (Motion Coupling in Virtual Environments, MOCOVE).

Systematic observations are required to compare the side effects and aftereffects of an environment where both simulated ship motion and real ship motion exist and are not coupled to each other, that one may refer to as a "decoupled" virtual environment (VE). These effects can be quantified experimentally using the following environments:

- **VLO + uncoupled VE** – The uncoupled VE is a virtual environment in which no attempt has been made to correlate it with the motion of the VLO. The scene never changes elevation as the participants goes up and down
- **VLO + MOCOVE** – The MOCOVE device senses the motion of the VLO and couples this back into the VE. The visual perspective change in the VE is as similar as possible to what would occur if the participants were directly viewing the real surroundings.
- **VLO + natural coupling** – Here, the participants are not in a virtual environment. Instead, they have natural vision into the lighted laboratory, thus permitting them to see their environment with natural coupling to the motion of the VLO.

In all environments, a small set of experienced observers reported their motion sickness, disorientation and postural side effects and aftereffects.

Coupling was effected through the integration of a Motion Coupling in Virtual Environments (MOCOVE) prototype system. The current prototype MOCOVE system is capable of inertial tracking of the motion of a platform and updating the simulated visual perspective of an observer in a motion environment similar to what one would experience aboard a Naval ship (see Figure 2). This was demonstrated using the Naval Research Laboratory's (NRL) ship motion simulator (SMS) (Figure 3).

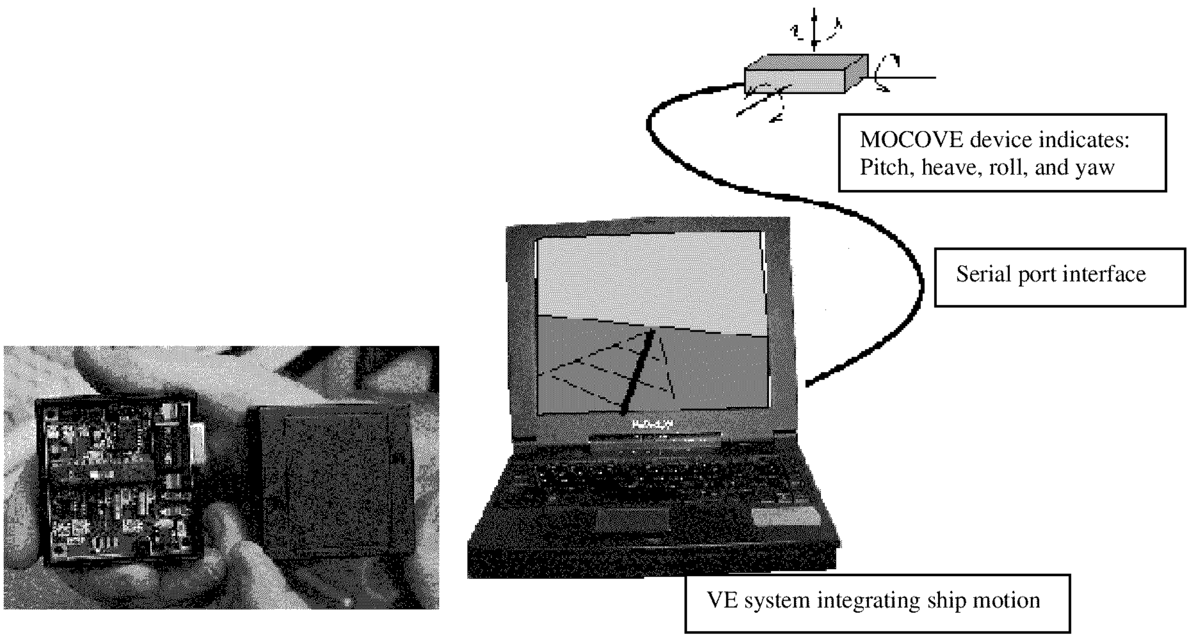

Figure 2: MOCOVE device. *Left:* The actual hardware. *Right:* Schematic for implementing MOCOVE. The device senses Pitch, Heave, Roll and Yaw motion and transmits this information, via serial interface, to a computer system. This information is integrated with the currently running simulation to produce an aggregate change in the visually presented scene that is coupled to the physical environment's motion.

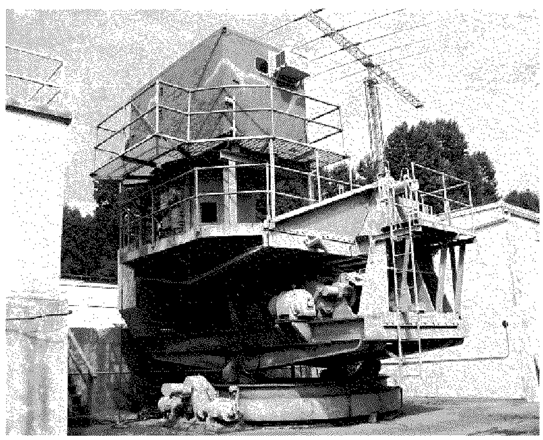

Figure 3: Naval Research Laboratory's Ship Motion Simulator (SMS). Capable of +/- 14 degrees pitch; +/-5 degrees roll, 8 s period.

The MOCOVE system currently tracks three degrees of freedom (roll, pitch and heave), as follows. If the MOCOVE device is rotated about its axis to any position, the vector sum of 3 of its axes must be equal to 1 G pointing in the direction of the center of the earth. Accelerations from or to the earth's center modify this vector's magnitude by the appropriate acceleration. The vertical heave component is computed by integrating the acceleration over time. The shipboard environment is more complex – except at the ship's center of gravity, there are centrifugal forces involved. Due to low pitch and roll rates, these forces are negligible compared to those associated with heave and ignore them. Appendix A provides a portion of these calculations.

The basic experiment required six experienced observers to evaluate combinations of VLO and passive viewing of a scene with and without motion coupling, during 15-minute exposures. The VLO ran at 0.2 Hz, 1.9 m peak-to-peak amplitude. Participants reported that the natural environment produced the least amount of side effects, while the virtual environment coupled to the VLO via MOCOVE produced slightly more side effects. However, participants experienced a far greater level of side effects in the uncoupled VE case, that is, with

MOCOVE turned off. Thus, not only is the vestibular system itself a poor indicator of motion direction, but the visuo-vestibular system can be easily decoupled. At the same time, the above results indicate that this coupling can be re-introduced using basic VE techniques.

Conclusions

Experiment 1 examined a "best-case scenario" in which a minimally provocative ship motion stimulus was combined with a non-provocative flight simulator. It was expected that combining these minimal stimuli would cause MAS. In fact, although following the ship + flight sim condition participants reported negligible symptoms of nausea and simulator sickness and no balance disturbances were apparent, they could not see as well in a dynamic visual environment as they could prior to exposure to the flight simulator aboard ship. This finding is critically important, when two facts are considered. First, participants were exposed to a minimum stimulus. Second, in terms of decreased readiness, for instance with respect to pilots, loss of one line of dynamic visual acuity equates to the pilot missing their "wingman's" position, or the inability to discriminate a "bogie", when the pilot makes a quick head movement to scan their visual scene. This can be deadly in the highly dynamic environment of air combat maneuvers. Experiment 2 took these basic findings one step further, using more realistic stimuli. Again, the most provocative condition was one in which scene motion and physical motion were decoupled. Importantly, Experiment 2 demonstrated that by reintroducing this coupling, through the use of MOCVOE technology, the experienced sickness was reduced.

These results are of critical import in light of the recent, profound, changes in training doctrine occurring throughout the military. As U.S. forces continue to modernize and react to new threats, the most crucial changes involve delivering this training. Specifically, systems are being deployed with embedded training capabilities that may be used while the system itself is in motion. For example, virtual training systems are currently being developed for the specific purpose of placement aboard ships for use at sea. Land systems are being designed so that gunners may practice their art while their vehicle is underway and they are not otherwise engaged. The currently reported work demonstrates that an external and unrelated motion environment superimposed upon a virtual environment creates a level of side effects that are greater than the mere addition of the side effects one would experience from either environment alone. Given the great benefit ascribed to embedded training, a significant interfering factor such as this must be mitigated to the degree possible. Our current research efforts suggest one method achieving this.

References

Baltzley DR, Kennedy RS, Berbaum KS, Lilienthal MG and Gower DW. The time course of postflight simulator sickness symptoms. *Aviat, Space Environ Med*, 1989; 60:1043-1048

Brooks, T. (1999). Star Wars Episode I: The Phantom Menace, Unabridged [CD], Tracks D1-01 to D1-14, and D2-16 to D2-30 (Duration: 1:03:04; Equivalent to book chapters 1, 2, & 6) New York, NY: Random House Audio Publishing Group, Inc.

Bruner JM. Seasickness in a destroyer escort squadron. *United States Armed Forces Medical Journal*, 1955; 6(4): 469-490.

Cohn, J.V, Mead, A., Giebenrath, J & Burns, J (2002). A report from the filed: Implementing new technologies for training system design and evaluation. *Manuscript in preparation.*

Kennedy RS, Berbaum KS and Lilienthal MG (1992). Human operator discomfort in virtual reality systems: simulator sickness-causes and cures. In S Kumar (Ed.) *Advances in Industrial Ergonomics and Safety IV*, (pp. 1227-1234). Taylor and Francis.

Kennedy RS and Frank LH. A review of motion sickness with special reference to simulator sickness (1985, Report No. NAVTRAEQUIPCEN 81-C-0105-16). Orlando, FL: Naval Training Equipment Center, Naval Air Systems Command.

Kennedy RS, Lane NE, Berbaum KS and Lilienthal MG. Simulator sickness questionnaire: An enhanced method for quantifying simulator sickness. *The International Journal of Aviation Psychology*, 1993;3:203-220.

Lawson, B.D., Graeber, D.A., Mead, A.M., and Muth, E.R (2001). Signs and symptoms of human syndromes associated with Synthetic Experiences (SEs). Chapter 34, from The Handbook of Virtual Environments Technology, Stanney (ed.) Lawrence Erlbaum Associates, Inc., Mahwah, NJ.

Lawther A and Griffin MJ. Prediction of the incidence of motion sickness from the magnitude, frequency, and duration of vertical oscillation. *J Acoust Soc Am*, 1987;82:957-966.

Morales MF. Motion sickness: Physical considerations regarding its etiology. In: Panel on Psychology and Physiology (Eds.), *A survey report on human factors in undersea warfare.* Washington, D.C.: Committee on Undersea Warfare National Research Council.

Muth ER, Stern RM, Thayer JF and Koch KL. Assessment of the multiple dimensions of nausea: The Nausea Profile. *Journal of Psychosomatic Research*, 1996; 40:511-520.

Reason JT, Brand JJ. Motion sickness. London: Academic Press;1975. p. 181-86.

Royal L, Jessen B and Wilkins M. Motion sickness susceptibility in student navigators. *Avia Space Environ Med*, 1984;55:277-280.

Smith MJ, Cohen BGF and Stammerjohn LW. An investigation of health complaints and job stress in video display operations. *Human Factors*, 1981;23:387-400.

Strongin TS and Charlton SG. Motion sickness in operational bomber crews. *Aviat Space Environ Med*, 1991;62:57-59.

Tyler DB and Bard P. Motion Sickness. *Physiol. Rev*, 1949;29:311-369.

Ungs TJ. Simulator induced syndrome: evidence for long-term aftereffects. *Aviat Space Environ Med*, 1989; 60:252-255.

Appendix A: Equations for resolving G and Heave

Each accelerometer has 2 axes (x and y). We wish to compute the vector g. *Vx* and *Vy* are normalized readings from the X and Y-axes.

Solving for G

The readings *Vx* and *Vy* are the projections of *g* onto the *X* and *Y* vectors. *X* and *Y* are perpendicular.

$$V_x = \vec{g} \cdot \vec{x} = |\vec{g}||\vec{x}| \cos\phi \qquad (1)$$

$$V_y = \vec{g} \cdot \vec{y} = |\vec{g}||\vec{y}| \cos(\phi + \frac{\pi}{2}) \qquad (2)$$

$$|\vec{g}| = \frac{V_x}{|\vec{x}|\cos\phi} = \frac{V_y}{|\vec{y}|\cos(\phi + \frac{\pi}{2})} \qquad (3)$$

Solving for the angle of G

We now solve for *g*'s angle, ϕ.

$$\frac{V_x}{\cos\phi} = \frac{V_y}{\sin\phi} \qquad (4)$$

$$\frac{\cos\phi}{\sin\phi} = \frac{V_x}{V_y} \qquad (5)$$

$$\phi = \tan^{-1}\frac{V_x}{V_y} \qquad (6)$$

Solving for G magnitude

To avoid division by zero we select the appropriate relation. The units are based on the normalized values of *Vx* and *Vy*.

$$|\vec{g}| = \begin{cases} \frac{V_x}{\cos\phi} & \cos\phi \neq 0 \\ \frac{V_y}{\sin\phi} & \cos\phi = 0 \end{cases} \qquad (7)$$

Solving for Heave

Integrate *g*'s vertical projection over the time step (currently dt = 1/4 s).

$$V_s = \int_0^t (|\vec{g}||\vec{y}| \sin\phi - 1)dt \qquad (8)$$